Validation of Feed and Manure Data Collected on Wisconsin Dairy Farms

J. M. Powell,*[1] D. B. Jackson-Smith,† D. F. McCrory,‡[2] H. Saam,‡[3] and M. Mariola§
*USDA-Agricultural Research Service, Dairy Forage Research Center, 1925 Linden Drive West, Madison WI, 53706
†Department of Sociology, Social Work and Anthropology, Utah State University, 216 H Old Main Building, Logan, 84322
‡Department of Soil Science, University of Wisconsin-Madison, 1525 Observatory Drive, Madison, 53706
§Rural Sociology Program, The Ohio State University, 2120 Fyffe Road, Columbus, 43210

ABSTRACT

An on-farm study of 54 representative Wisconsin dairy farms was conducted to evaluate the influence of biophysical and socioeconomic factors on overall feed, fertilizer, and manure nutrient use. This report validates 1) how well data on cow diets, feed analyses, and milk production reflected established feed-milk-manure relationships; and 2) how well farmer-recorded data on manure land application reflected literature values of manure N and P excretion, collection, and loss. Calculated feed N and P use efficiencies (18 to 33% and 18 to 35%, respectively) fell within ranges expected for dairy farms. This suggested that our on-farm methods of data collection provided reliable information on relationships among feed N and P intake, secretions in milk, and excretion in manure. On stanchion farms, there were no differences between farmer estimates (kg/farm) of manure P collected (1,140) and land-applied (1,210) and what would be calculated from the literature (1,340). On freestall farms, there were no differences in amounts (kg/farm) of manure P collected (2,889), land-applied (2,350), or literature estimates (2,675). Manure P applications (kg/ha) to tilled cropland would be similar using either farmer estimates of manure collected and land-applied, or literature estimates. The data provided a snapshot of Wisconsin industry practices, as well as information on the range of feed and manure management practices on individual dairy farms. Improvements to data collection methods would require increased skill and training of both farmers and those responsible for assisting farmers in on-farm data collection and analyses.

Key words: feed, manure, nutrient use efficiency, on-farm data

INTRODUCTION

Over the past 10 yr, concern has grown about the potential buildup and loss of manure nutrients to groundwater, lakes, and streams. More recently, these water quality issues have been joined by heightened awareness of the potential for livestock operations to emit pollutants into the atmosphere, which can adversely affect air quality and enhance nutrient enrichment and acidification of land and surface water resources (NRC, 2003). To respond to these concerns, federal and state agencies have increasingly directed policy toward mitigation of the negative environmental impacts of animal manure. Although most regulatory agencies use the number of animals per farm to target manure management policy, it has become increasingly evident that farms of all sizes can generate environmental impacts, and certain management practices, such as feed and herd management, may have large impacts on manure nutrient concentrations, soil nutrient buildup, and environmental contamination.

With recent and impending passage of government regulations pertaining to environmental impacts from animal agriculture, many livestock producers seek new ways to track and improve the management of nutrients contained in feed and manure. Our ability to develop and implement sound feed and manure management strategies depends not only on production biophysical factors (e.g., livestock nutrient requirements, soils, weather, cropping systems), but also on socioeconomic conditions that influence farmers' nutrient management behavior. For these reasons, farmer involvement in technology and policy development is required to identify the real barriers and opportunities for improving nutrient management on livestock farms. As the demand grows for measurable improvements in nutrient management based on real-farm data, farmers will be increasingly held accountable for tracking nutrient inputs, outputs, and use on their operations. Such on-farm data collection moves beyond the assumptions embedded in mathematical nutrient management models and helps reveal the farm-level reality of nutrient management and farmers' ability to track it. The present study was conducted with that goal in mind.

A basic function in dairy farming is to import nutrients (e.g., feed, bedding, fertilizer, nitrogen fixation by legumes), transform them into exportable products (e.g., milk, meat, replacement stock), and generate an economic return (Grusenmeyer and Cramer, 1997). Whole-farm nutrient balance (Koelsch, 2005), or the difference between farm nutrient imports and exports, provides a general indicator of whether a farm risks nutrient buildup and environmental contamination. Animal:cropland ratios, or relationships between livestock numbers (and the manure they produce) and cropland area available for manure application (Beegle, 1994; Saam et al., 2005), provide an alternative indicator of whole-farm environmental performance. Whereas these and other whole-farm indicators may indicate overall pollution risk, they cannot address how nutrient management in one production component (e.g., feed) might affect nutrient cycling in other production components (e.g., manure nutrient recycling through soils, crops) and the relative impact of each component's management on profitability and the environment (Kohn et al., 1997; Dou et al., 1998).

Various approaches have been used to collect data on nutrient management practices on dairy farms. For example, Jonker et al. (2002) used a mail survey to collect feed, milk production, and composition information on 454 dairy farms in Pennsylvania, Maryland, Virginia, West Virginia, and Delaware. This information was used to estimate herd management impacts on feed N use efficiencies. This study and its predecessor (Kohn et al., 1997) concluded that improvements in feed management are the most cost-effective means of reducing N losses from dairy farms. More detailed information on actual feed, fertilizer and manure management practices requires more intensive, more direct data collection, and this has been achieved using relatively few farms (Klausner, 1993; Dou et al., 1998). To provide a snapshot of nutrient management for the wider dairy farm population, there is the need to define the total farm population, then randomly select and collect data from representative farms. The "On Farmers' Ground" (**OFG**) research project (NPM, 2005) was established in 2002 with 54 representative Wisconsin dairy farms to evaluate impacts of regional climate and soil differences, farm size, and operational features on overall nutrient use including when, where, and how much manure was land-spread.

The objective of this initial report is to evaluate the accuracy of key OFG data. To accomplish this task, 2 basic questions were posed: 1) how well does data collected on-farm regarding cow diets, feed analyses, and milk production reflect established feed-milk-manure relationships; and 2) how well does farmer-recorded data on manure spreading reflect literature values of manure N and P excretions and losses, and other literature estimates of manure collection and spreading. An additional objective was to evaluate and recommend survey techniques that could facilitate and improve the collection of reliable feed and manure management data collected on dairy farms.

MATERIALS AND METHODS

Stratified random sampling procedures were used to provide a study population of 54 dairy farms that represent the range of farm sizes, livestock densities (cow:cropland ratios) and manure recycling capacities typical of the Wisconsin dairy industry (Saam et al., 2005). The farms were distributed across the 12 principal dairy counties, major soil types, and watersheds of impaired water bodies in Wisconsin (Powell et al., 2005). The hilly southwest (**SW**) is characterized by well-drained silt loam soils; the relatively flat northeast (**NE**) region has less permeable clay loam and loam soils; and the undulating south-central (**SC**) region has landscapes and soils somewhat intermediate to those of the SW and NE (Hole, 1976).

Four to 5 visits per farm and data collection were done during the period from September 2002 to March 2005. Survey instruments were designed to compile an overall picture of each farming operation, including herd size, cropping patterns, livestock facilities, management practices, and motivations and goals related to feed, fertilizer, and manure management. Aerial photographs validated and recorded farm and field boundaries, which were coded and digitized for use throughout the study. The collection of field-level data on nutrient inputs, outputs, and management was initiated in March 2003 and concluded in September 2004. Phone calls to farmers and their feed and crop consultants were made to verify collected data and solicit new information as necessary. Farmer attrition, incomplete data, and other factors provided verifiably reliable feed and manure management information on 33 to 52 of the original 54 farms, depending on the type of data collected.

Herd and Feed Management

Farm operators were asked the number of cows (lactating and dry) and heifers kept on the farm. Questions were also asked about feed management, such as whether the lactating herd was subdivided into different feeding groups, how often rations were balanced, the use of milk production technologies, and milking frequencies. The types and amounts of feed being offered the day of the interview were recorded for each feeding group. Estimates of feed refusals were not col-

lected. Samples of each feed component and TMR were taken and frozen until analyzed.

Manure Management

A log was developed to track when, where, and how much manure was spread daily from March 2003 to September 2004. Recordings were made of manure type (semisolid, liquid, bedded pack), spreader type, fields receiving the manure, and the relative fullness of each spreader upon departure for manure land spreading. Manufacturer information on spreader capacities was used to estimate manure mass spread. Labeled containers were provided and farmers were instructed on collection of representative manure samples (Peters et al., 2003). Semisolid manure samples of approximately 500 g were taken every 2 mo and liquid manure samples of the same weight were taken periodically during the period when farmers removed and land-spread manure from storage. Farmers kept manure samples frozen until pick up by the research team, and samples remained frozen until analyzed. The amount of manure N and P land-applied was calculated by multiplying manure mass in a spreader by the DM, N, and P content of manure samples corresponding to the spreading period.

Feed and Manure Analyses

Feed subsamples were oven-dried (60°C, 72 h), manure subsamples were acidified (6 mL of 0.7 N H_2SO_4 per 20 g of wet manure) and then freeze-dried, and both feed and manure samples were ground to pass a 2-mm screen. Total N content of dried feed and manure samples was determined by combustion assay (Leco FP-2000 nitrogen analyzer, Leco Instruments Inc., St. Joseph, MI). Ground feed and manure subsamples were oven-dried (100°C, 24 h) for DM determination. Total P in feed and manure was determined by ashing subsamples for 24 h at 500°C in a muffle furnace, followed by ash dissolution in HCl and solution P analysis using direct current plasma emission spectroscopy. For non-TMR diets, CP (N content × 6.25) and P levels were calculated as the proportional combination of each feed component DM and their associated CP and P concentrations. For TMR diets, CP and P concentrations were determined directly on TMR samples.

Verification of Lactating Cow Diets. Two approaches were used to validate farmer-provided information on diets and milk production: 1) feed N use efficiency (**FNUE**) and feed P use efficiency (**FPUE**) were calculated using Equations 1 and 2; and 2) cow N balances (**CNB**) were calculated using Equation 3:

$$\text{FNUE} = 100 \times [\text{Milk N production (g/cow per d)/}$$
$$\text{Feed N intake (g/cow per d)]} \qquad [1]$$

$$\text{FPUE} = 100 \times [\text{Milk P production (g/cow per d)/}$$
$$\text{Feed P intake (g/cow per d)]} \qquad [2]$$

$$\text{CNB (g/cow per d)} = \text{Apparent feed N intake} \quad [3]$$
$$- (\text{milk N} + \text{manure N}).$$

Feed N and P intakes were derived from farmer-defined amounts of feed DM offered to lactating cows, multiplied by diet N and P concentrations. Milk N and P secretions were calculated by multiplying farmer-reported milk production by milk N and P concentrations of 4.9 (Nennich et al., 2005) and 0.9 g/kg (Beede and Davidson, 1999), respectively. For lactating cows, manure N excretions (fecal N + urinary N) were derived from the equation [milk production (kg) (2.82] + 346 (Nennich et al., 2005) and manure P excretions were calculated as the difference in feed P intake and milk P secretions (Beede and Davidson, 1999).

Verification of Manure Applications. An objective of this study was to assess the relative accuracy of total manure N and P applications as recorded by farmers. To accomplish this, total manure N and P applications (kg/farm), or the sum of field manure N and P applications from October 2003 to September 2004 in the manure application records (**APP**) were compared with 1) the sum of calculated manure N and P excretions by lactating cows, dry cows, and heifers for each herd (Powell et al., 2005), and 2) to farmer estimates of apparent manure collection (**AMC**) calculated from information provided during the first interview. In brief, AMC was a measure of potential manure N and P available for land application calculated as the difference in total manure N and P excreted by the dairy herd and the amount of manure N and P uncollected during periods of the year when lactating cows, dry cows, and heifers were kept outdoors (Powell et al., 2005).

Percentage manure N excreted apparently not spread ($perEXC_N$) was used as an indicator of manure N losses during manure handling and storage. This was calculated using equation 4:

$$\text{perEXC}_N = 100 \times [(\text{EXC}_N - \text{APP}_N)/\text{EXC}_N]. \qquad [4]$$

Manure data validations also included comparisons of apparent manure P collection (AMC_P) and manure P land-applied (APP_P). Average AMC_P and APP_P values were also compared with the general literature value of 80% manure collection efficiency assumed in national studies of manure management on dairy farms (Kellogg et al., 2000; Gollehon et al., 2001).

Statistical Analyses

Differences in diet DM, CP, and P offered to lactating cows, milk production, FNUE, and FPUE due to herd

Table 1. Regional herd and cropping characteristics of the study dairy farms in Wisconsin[1] (adapted from Powell et al., 2005)

Production components	Region			
	Southwest (n = 18 farms)	South central (n = 18 farms)	Northeast (n = 18 farms)	All (n = 54 farms)
Herd size, % of farms				
1 to 49 cows	31	26	16	25
50 to 99 cows	56	53	68	59
100 to 199 cows	0	10	5	6
200+ cows	13	11	11	10
Animal type, no./farm				
Lactating cows	49 (11–270)	53 (23–480)	52 (32–387)	52 (11–480)
Dry cows	9 (2–50)	10 (0–75)	8 (3–46)	9 (0–75)
Young heifers[2]	14 (0–30)	20 (5–173)	15 (5–145)	15 (0–173)
Mature heifers[2]	20 (0–55)	28 (5–247)	35 (0–245)	28 (0–247)
Land use, ha/farm				
Total operated cropland	65 (15–257)	90 (38–442)	82 (30–339)	80 (15–442)
Corn grain	14 (0–69)	30 (0–138)	12 (0–54)	15 (0–138)
Corn silage	5 (0–108)	11 (0–130)	15 (6–132)	11 (0–132)
Soybeans	0 (0–26)	0 (0–300)	0 (0–53)	0 (0–300)
Alfalfa	22 (4–99)	25 (8–112)	26 (13–109)	25 (4–112)
Small grain	0 (0–13)	0 (0–16)	0 (0–61)	0 (0–61)
Pasture	17 (0–52)	4 (0–75)	1 (0–6)	4 (0–75)

[1]Median (minimum – maximum). For data sets that do not have a normal distribution, a median is a better measure of central tendency than a mean.

[2]Young heifers (≤7 mo) and mature heifers (>7 mo).

size and feed management practices were delineated using the GLM procedure (SAS Institute, 1990). When significant differences were detected, mean differences were delineated using the least significant differences procedure. Differences in the amount (kg/farm) and percentage of excreted manure P spread as estimated by AMC_P and APP_P were determined by regression analyses. The GLM procedure (SAS Institute, 1990) was used to test if AMC and APP provided similar manure P applications rates (kg/ha) to tillable cropland. For this analysis, tillable cropland was defined as the sum of land areas in corn, oats, barley, other small grains, nonhay "other crops", 33% of the area in hay (this assumes that alfalfa fields are tilled every 3 yr), and 65% of the area reported in soybeans (the state approximate average for proportion of total soybean area that is tilled; Saam et al., 2005).

RESULTS AND DISCUSSION

Dairy Herd Size and Management Practices

The dairy herd and cropping system characteristics of the OFG farms (Table 1) were similar to the general dairy farm population in these regions (Jackson-Smith et al., 2000). Most (60%) dairy farms were of a moderate size, milking between 50 and 100 cows, with a median herd size of 60 cows. The highest percentage (21%) of farms having greater than 100 cows was found in the SC part of the state, followed by the NE (16%) and the SW (12%). Most dairy cows in Wisconsin are housed in stanchions or tie-stall barns. This was reflected in the farm sample pool where only 31% of farms use free-stall housing for their milking herd and only 17% were using a parlor system for milking (data not shown).

Dairy Diet Composition and Quality

Approximately one-third of the study farms fed TMR; the remaining two-thirds did not feed TMR, but provided feeds individually. There were no significant ($P < 0.05$) differences in diet DM offered, or in dietary CP or P concentrations between farms feeding TMR and non-TMR. The CP and P concentration in diet components, composite non-TMR diets, and TMR are given in Table 2. Average diet CP contents of 172 g/kg are somewhat greater than the approximately 165 g/kg necessary for maximizing milk production and quality for cows fed similar diet components (Broderick, 2003). Average P concentrations in corn silage (2.5 g/kg) and alfalfa hay (3.1 g/kg) on study farms were almost identical to reported national averages (Berger, 1995), NRC book values (NRC, 2001), and levels determined previously on Wisconsin dairy farms (Powell et al., 2002). In the latter Wisconsin study, average diet P concentrations of 4.0 g of P/kg of DM were determined. Average diet P concentrations in the present study of 4.1 g of P/kg indicate that on average dairy producers in Wisconsin may continue to feed P above NRC-recommended level of 3.8 g of P/kg.

Table 2. Dry matter, CP, and P contents, and DM offered of major dietary components on the study dairy farms in Wisconsin

Feed	Farms, n	Statistic	DM, g/kg	CP, g/kg of DM	P, g/kg of DM	DM offer, kg/cow per d
Non-TMR	26	Mean	616	171	4.2	22.3
		5th percentile	569	167	4.0	20.8
		95th percentile	663	175	4.4	23.9
TMR	15	Mean	521	173	4.0	22.4
		5th percentile	494	167	3.9	20.3
		95th percentile	549	180	4.2	24.6
Corn silage	17	Mean	403	90	2.5	3.8
		5th percentile	370	79	2.3	2.9
		95th percentile	438	101	2.7	4.8
Corn silage-haylage mix	10	Mean	492	143	3.1	10.2
		5th percentile	354	117	2.2	7.8
		95th percentile	629	169	3.7	12.7
Alfalfa hay	25	Mean	888	178	3.1	5.0
		5th percentile	880	168	2.8	3.1
		95th percentile	895	188	3.4	7.0
Alfalfa haylage	19	Mean	453	171	3.1	7.7
		5th percentile	402	157	2.9	5.6
		95th percentile	504	185	3.4	9.8
High moisture shell corn	9	Mean	791	140	2.9	5.5
		5th percentile	760	96	2.5	4.4
		95th percentile	821	184	3.4	6.6
Grain mix	21	Mean	863	147	5.7	6.7
		5th percentile	851	126	4.5	5.7
		95th percentile	875	168	6.9	7.7
Protein mix	21	Mean	900	380	8.5	2.4
		5th percentile	885	345	6.8	1.8
		95th percentile	917	416	10.1	3.0
Minerals	14	Mean	NR[1]	17	78.4	0.14
		5th percentile	NR	<1	51.4	0.08
		95th percentile	NR	34	105.3	0.20

[1]NR = Not recorded.

Feed N and P Use Efficiencies

Statewide and regional statistics for feed DM, CP and P concentrations, milk production, and FNUE and FPUE are presented in Table 3. No significant ($P < 0.05$) regional differences in diet CP or P concentrations, milk production, FNUE, or FPUE were observed. There were, however, farm size differences in production parameters. Dairy farms with the largest herds (>200 lactating cows) fed diets having greater P concentrations than farms having the smallest herds (1 to 29 cows). Milk production was significantly higher on farms having 200 or more lactating cows than on farms having 30 to 99 cows. Milk production on farms having the smallest herds (1 to 29 cows) was significantly lower than on farms having 30 or more dairy cows. Feed N use efficiencies were highest ($P < 0.05$) on the largest farms.

Dairy nutrition and management can reduce manure N excretion and environmental loss through a better definition and targeted use of feed inputs; improvements in animal productivity; improved knowledge of the biology involved and the nutrient content of feeds; and by feeding cows in groups based on productivity and nutritional needs (Dou et al., 1998; St-Pierre and

Tharaen, 1999). Balancing rations has the potential to reduce dietary N intake, manure N excretion, and therefore, FNUE (Dou et al., 1998). On dairy farms in the present study, the use of TMR (n = 15 farms), balancing rations 4 times per year (n = 37), milking thrice daily (n = 3), and the use of Posilac (n = 9) all resulted in significant ($P < 0.05$) increases in milk production. Gains in FNUE were obtained on farms that used TMR, balanced rations, and milked thrice daily. Feed P use efficiencies were similar across regions, herd sizes, and whether TMR or Posilac were used or not, or whether cows were milked twice or thrice daily. Feed P use efficiencies were significantly greater on farms (n = 37) that balanced rations at least 4 times per year. In contrast to other suggestions (St-Pierre and Tharaen, 1999), feeding lactating cows in groups did not affect milk production, FNUE, or FPUE. In general, it was more common for dairy farmers in the NE to have adopted a range of productivity enhancing dairy management practices when compared with the other regions. For example, a higher percentage of farms in the NE balanced dairy rations at least 4 times per year, kept records on individual cows, and fed TMR. Possibly

Table 3. Statewide and regional values, and impact of herd size, feed management, and milking frequency on dietary CP and P concentrations, DMI, milk production, and feed N use efficiency (FNUE) and feed P use efficiency (FPUE) on dairy farms in Wisconsin

Parameter	Variables	CP, g/kg of DM	P, g/kg of DM	DM offered, kg/cow per d	Milk production, kg/cow per d	FNUE, %	FPUE, %
Statewide values	Mean	172	4.1	22.7	29.6	25.4	29.0
	5th percentile	168	4.0	21.5	27.6	23.9	26.6
	95th percentile	175	4.3	23.9	31.6	27.0	31.3
Regional values	Northeast	172	4.2	23.8	31.8	27.1	29.5
	South central	173	4.0	22.3	29.6	25.1	29.0
	Southwest	172	4.3	22.1	27.3	23.8	28.4
Herd class (lactating cows/farm)	1 to 29	169	3.7[b]	21.3	20.0[c]	18.2[c]	23.5[b]
	30 to 49	168	4.2[ab]	23.6	27.4[b]	24.2[b]	26.6[ab]
	50 to 99	173	4.2[ab]	21.8	29.7[b]	26.6[b]	32.1[ab]
	100 to 199	175	4.0[ab]	25.3	33.1[ab]	24.3[b]	24.4[b]
	200+	176	4.5[a]	23.0	38.7[a]	32.6[a]	34.6[a]
Use of TMR	Yes	172	4.0	23.1	33.5[a]	27.0[a]	28.9
	No	172	4.2	22.5	26.1[b]	24.1[b]	29.0
Balance rations ≥4×/yr	Yes	171	4.1	22.6	30.6[a]	26.5[a]	30.0[a]
	No	175	4.3	23.2	24.7[b]	21.0[b]	24.8[b]
Milk thrice daily	Yes	176	4.5	23.0	40.2[a]	32.6[a]	34.6
	No	171	4.1	22.7	28.8[b]	24.9[b]	28.7
Use Posilac	Yes	174	4.2	24.4	37.1[a]	29.0[a]	28.7
	No	171	4.1	22.4	27.7[b]	24.6[b]	29.1

[a–c]Within a variable category, means followed by different superscript letters differ significantly ($P < 0.08$).

because of this enhanced technology adoption, milk production per cow was found to be highest in the NE compared with the other regions of Wisconsin.

Apparent N and P Balances

Calculated FNUE and FPUE derived from farmer information on diets and milk production (Table 3) fell well within the range of values determined for much larger populations of dairy farms. For example, in a survey of 472 dairy farms located in the Chesapeake Bay drainage basin, Jonker et al. (2002) determined a fat-corrected milk production range of 22.4 to 33.6 kg/cow per d, and calculated FNUE of 24.5 to 32.3 across a wide range of herd feed practices. The close correspondence between FNUE and FPUE determined in the present study and those determined under field (Jonker et al., 2002) and extensive experimental conditions (Nennich et al., 2005) indicates that the methods used in the present study provided reliable information on relationships between the intake of N and P in feed, its secretion in milk and excretion in manure.

An additional way to evaluate the accuracy of on-farm data on diet and milk production is to calculate CNB, or the difference between the amount of N (CP/6.25) apparently fed (Table 3) and the sum of N secreted in milk and excreted in manure (Equation 3). Cow N balances were calculated for cows fed non-TMR and TMR (Figure 1). The average lactating cow on the 26 farms that fed non-TMR and the 15 farms that fed TMR had positive CNB. There was no significant difference,

however, in mean CNB on farms that fed non-TMR (32 g of N/d) and farms that fed TMR (58 g of N/d) due to great variability around these mean CNB.

Positive CNB signify that either calculations of feed N intake were higher than actual consumption, or estimates of milk N or manure N were too low. Milk production, based on bulk tank estimates, and manure N excretions, based on extensive data sets over the long-term (Nennich et al., 2005), are likely the most accurate of the feed-milk-manure components of the CNB (Equation 3). Most of the positive CNB may have been due to overestimates of feed N consumption or possible manure N losses during sample processing and analysis. Some farmers may offer feed in excess of consumption, and either feed orts to dry cows and heifers, or discard orts.

The amount of feed offered not consumed can be estimated by dividing apparent CNB by the N content of the feed. For example, farms that fed non-TMR had an average positive CNB of 32 g of N and non-TMR diets contained 27.4 g of N/kg [i.e., 171 g of CP/kg (Table 2) × 0.16 g of N/g CP]. On average, approximately 1.2 kg of diet DM (32 g of N/27.4 g of N/kg) was apparently overfed on farms feeding non-TMR. Using the same calculation, farms that feed TMR fed on average 2.1 kg of diet DM in excess of consumption.

Also, a portion of diet N consumed may not have been converted into milk or manure, but used for cow growth, pregnancy, etc. Whereas bulk tank estimates of milk production may reflect herd production, within-herd variability in milk production may be high, and some
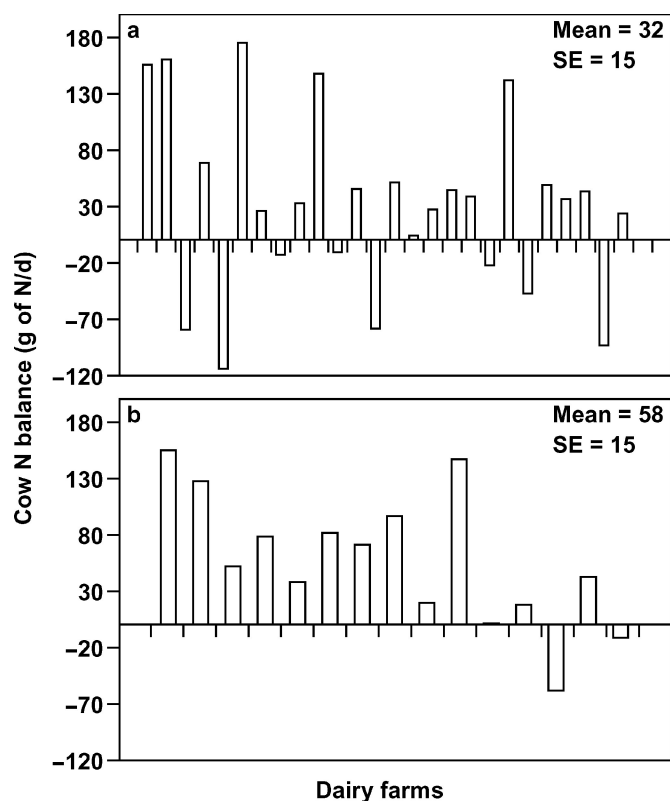
Figure 1. Estimated daily N balances (feed N – milk N – manure N) for lactating cows on dairy farms feeding a) non-TMR, and b) TMR.

milk may be discarded, kept for home consumption, or retained for feeding to calves. Although these and other factors may impact estimates of feed and milk production, the range of FNUE (18 to 33%) and FPUE (18 to 35%) determined in the present study (Table 3) fall within a range expected for dairy farms feeding similar feedstuffs and employing a wide array of herd and feed management practices (Jonker et al., 2002).

Manure Characteristics

The chemical characteristics of semisolid and liquid manure spread on the study farms during the period 2003–2004 are given in Table 4. There were few significant monthly differences in the chemical characteristics of semisolid manure. Concentrations of OM were higher during the period January–May than in other months; concentrations of N in semisolid manure were highest during the period March–May; and concentrations of P were higher in May than in January. Chemical characteristics of liquid manure were similar during the various stages of manure removal from pit storage. This indicates that farmers were able to successfully mix manure pit depths before manure removal and land-

application. On a wet weight basis, semisolid manure contained higher concentrations of OM, N, and P than liquid manure indicating that nutrients in semisolid manure would be less expensive to spread (i.e., less water) than liquid dairy manure.

The N:P ratios of both semisolid and liquid manure (range of 5.42 to 6.55; Table 4) are somewhat lower than the N:P ratio (8.0) of most grain crops (White and Collins, 1982). This implies that manure applications to meet a crop's N requirement would result in manure P additions in excess of crop needs. Conserving manure N from excretion, through storage and land, is needed to maximize the N and P fertilizer value of manure and avoid excessive manure P applications.

Relationships Between Diet and Manure Nutrient Concentrations

A previous study of dietary feeding practices on 98 Wisconsin dairy farms found significant relationships between P concentrations in lactating cow diets and P concentrations in their feces (Powell et al., 2002). Similar relationships were determined for dairy herds in the northeast region of the United States (Toor et al., 2005). In the present study, no relationships were determined between dietary CP concentrations and manure N, or between dietary P concentrations and manure P. The lack of relationships between diets and manure nutrient concentrations was likely due to the varying amounts and types of bedding added to semisolid manure and varying losses of N, and perhaps to a lesser extent P, during the handling and storage of semisolid and especially liquid manure.

Manure Production, Collection, and Land-Spreading

Various methods were used to validate on-farm data on manure production, collection, and land application. One method assessed potential manure N losses as the percentage difference between the amount of manure N excreted by the dairy herd and the amount of manure N land-applied (Figure 2). Comparisons of differences in manure excretion and land application to typical manure N losses during manure handling and storage reported in the literature offered an additional indirect method of evaluating the general accuracy of farmer-kept manure application records.

The average percentage difference between herd manure N excretion and manure N land-applied was 29% for dairy farms operating stanchions and 6% for those with freestalls (Figure 2). Fulhage et al. (2001) reported a general manure N loss range of 20 to 35% indicating that average manure N application estimates for OFG stanchion farms are perhaps more accurate than for

Table 4. Manure characteristics on the study dairy farms in Wisconsin

Manure type	Sampling period	Samples	Chemical characteristics, g/kg of wet weight			N:P
			OM	N	P	
Semi-solid	January	44	777[ab]	4.62[c]	0.87[b]	6.09
	March	60	797[a]	5.26[ab]	0.89[ab]	6.55
	May	69	740[abc]	5.46[a]	1.04[a]	6.02
	July	59	713[c]	4.83[bc]	0.99[ab]	5.98
	September	66	719[bc]	4.97[bc]	1.01[ab]	5.59
	November	42	722[bc]	4.85[bc]	0.92[ab]	6.19
	Mean	340	743[Ab]	5.03[A]	0.96[A]	6.05
Liquid	Pit full	60	646	3.76	0.64	6.36
	½ empty	16	576	3.70	0.66	5.96
	⅓ empty	36	627	3.65	0.64	6.20
	⅔ empty	36	614	3.88	0.68	5.92
	Almost empty	50	574	3.80	0.73	5.43
	Mean	198	611[B]	3.77[B]	0.67[B]	5.98

[a–c]Within a manure type, chemical characteristic means followed by different lower case letters are significantly different ($P < 0.0001$).

[AB]Between manure types, chemical characteristic means followed by different uppercase letters are significantly different ($P < 0.0001$).

freestall farms. These difference analyses had some farms application applying more manure N than their herd produced (negative bars in Figure 2) or than they reportedly collected (positive bars in Figure 2). These
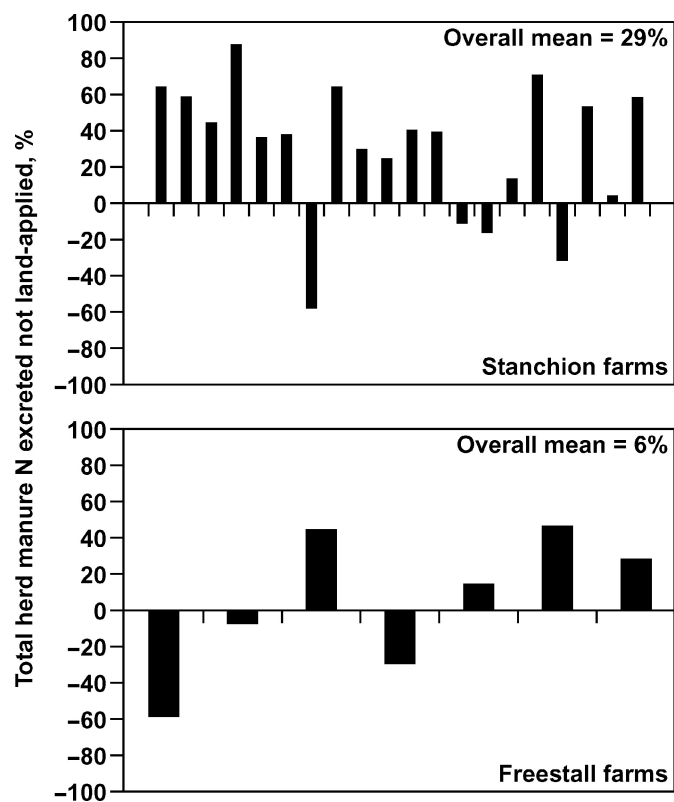
Figure 2. Manure N excreted not land-applied on stanchion and freestall dairy farms in Wisconsin.

discrepancies were likely due to various possible errors associated with manure application records, including 1) land-applied stored manure did not reflect annual herd manure production (i.e., if manure applied included manure stored from a previous year, then manure application records overestimated stored manure applied, and vice versa); 2) manure spreader was not always fully loaded, although farmer indicated it as "1 load"; 3) reliance on a single manure type per farm to estimate nutrient content of all manure applied. Although the study focused on the principal manure type (that generated by lactating cows, which accounts for 85 to 90% of the manure on Wisconsin dairy farms; Powell et al., 2005) on each farm, most farms had multiple types, albeit with lesser amounts of the other types. Thus, a farmer may have land-applied manure generated by dry cows, but the study treated it as if it were from lactating cows; 4) unrepresentative or poorly handled manure samples; and 5) inaccurate or illegible records kept by farmers.

Manure P is much less susceptible than manure N to losses during manure handling and storage. For this reason, differences in manure P should provide comparisons of AMC as determined in a previous study (Powell et al., 2005), and amounts of manure P applied as recorded by farmers in APP. Differences in amounts of manure P applied calculated by AMC and APP for stanchion and free-stall operations are illustrated in Figure 3. For the 24 stanchion operations, there was no difference ($P < 0.05$) between the average amount of manure P collected (AMC = 1,140 kg of manure P/farm) and what was land-applied (APP = 1,210 kg of manure P/farm); both averages were close to the 1,340 kg of ma-
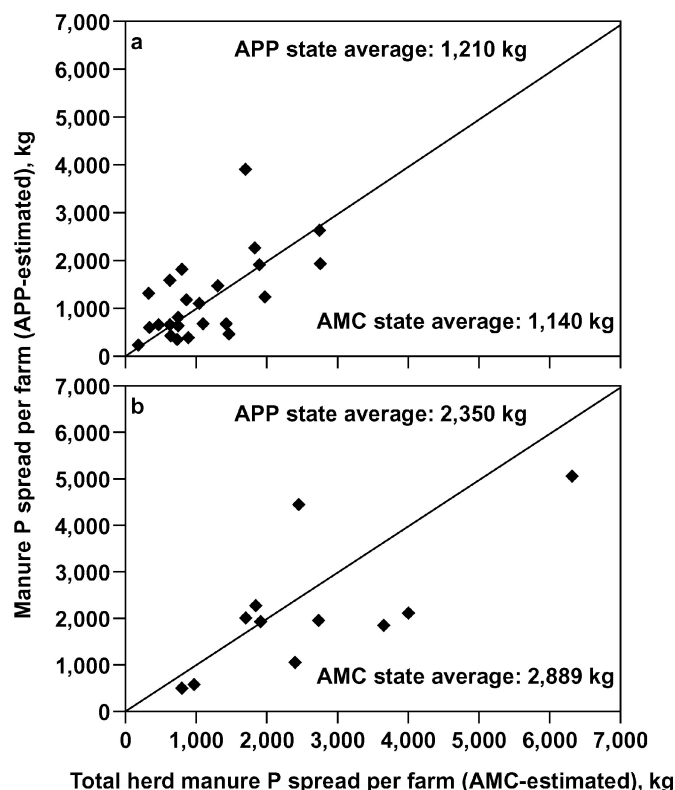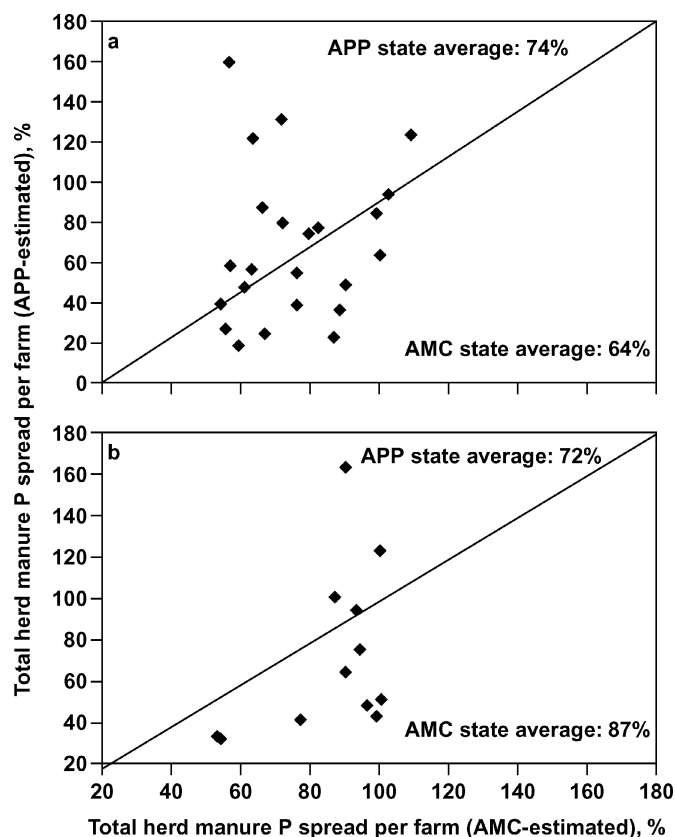
Figure 3. Comparison of whole-farm manure P applications estimated by apparent manure collection (AMC) and manure application records (APP) on a) stanchion, and b) freestall dairy farms in Wisconsin.

Figure 4. Comparison of percentage total herd manure P applied estimated by apparent manure collection (AMC) and manure application records (APP) on a) stanchion, and b) freestall dairy farms in Wisconsin.

nure P/farm that would be estimated using the average manure collection efficiency of 80% (Kellogg et al., 2000; Gollehon et al., 2001). Regression analyses of manure P application estimates (Figure 3) determined that slope = 1 ($P < 0.05$) indicating that AMC and APP made similar estimates of the amount of manure P land-applied on stanchion farms.

Somewhat similar results were obtained for 13 freestall operations (Figure 3). There were no significant differences in average amounts of manure P applied estimated using AMC (2,889 kg/farm) or APP (2,350 kg/farm) data. Both estimates of manure P application were similar to the 2,675 kg of manure P/farm available for application using the 80% manure P capture rate. Average manure P land-applied on free-stall operations (2,620 kg/farm) was significantly ($P < 0.05$) greater than manure P applied on stanchion farms (1,175 kg/farm). As with findings on stanchion farms, regression analyses determined that slope = 1 ($P < 0.05$) indicating that AMC and APP made similar estimates of the amount of manure P land-applied on free-stall farms.

On stanchion farms, there was no difference ($P < 0.05$) between percentage manure P collected (64%) de-

termined by AMC and the percentage land-applied (74%) calculated from manure application records (Figure 4). Both average values were somewhat lower than the 80% collection efficiency suggested by Gollehon et al. (2001) and Kellogg et al. (2000). Average manure P land-applied on Wisconsin freestall dairy farms determined by AMC was 87%, which was significantly ($P < 0.05$) higher than the 72% manure P applied as calculated from manure application records. Regression analyses indicated that AMC and APP provided different estimates (slope ≠ 1; $P < 0.05$) of manure P capture and land-applied on both stanchion and free-stall farms.

From a manure management perspective, perhaps the most important nutrient management question to pose is how would differences in manure P collection and spreading (Figures 3 and 4) impact field manure P application rates. For both stanchion and freestall farms, manure P application rates to tilled cropland would be statistically similar ($P < 0.05$) using either AMC or APP (Figure 5). These applications would also be similar if an overall average manure collection effi-
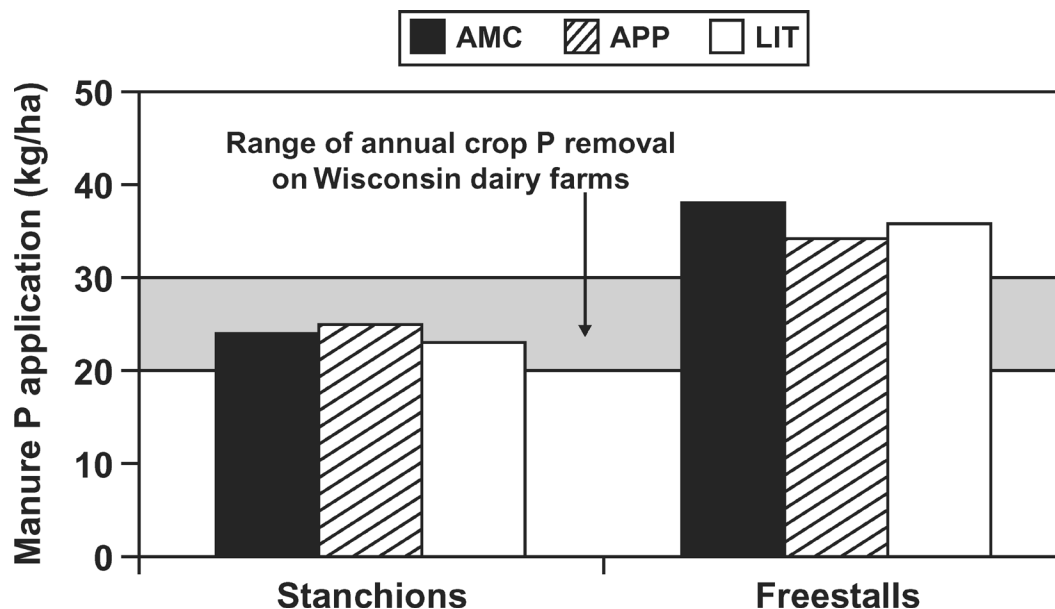
Figure 5. Comparison of average manure P applications to tillable cropland: apparent manure collection (AMC), manure application records (APP), and literature (LIT) estimates on stanchion and freestall dairy farms in Wisconsin.

ciency of 80% (Kellogg et al., 2000; Gollehon et al., 2001) were assumed. Average manure P application rates (39 kg/ha) to tilled cropland on free-stall farms would be significantly greater than application rates (25 kg/ha) on stanchion farms, and perhaps in excess of the 20 to 30 kg/ha range of P removal rates for most crops grown on Wisconsin dairy farms. Per livestock unit, there are no differences in the amount of cropland available on freestall and stanchion dairy farms (Saam et al., 2005). A principal likely reason for differences in manure P application rates is that significantly less manure is collected and therefore available for land-spreading on stanchion than on freestall farms (Powell et al., 2005), and that bedding and manure handling systems make it more difficult to get a representative manure sample on stanchion farms.

CONCLUSIONS

The data collected on representative dairy farms during this study provided a snapshot of industry practices in Wisconsin, as well as information on the range of feed and manure management practices on individual farms. Improvements to the data collection methods used in this study would require increased skills and training of both farmers and those responsible for assisting farmers in data collection and analyses. On-farm data collection requires knowledge of dairy farming practices including knowing the range of probable input–output relationships for different farm compo-

nents. Surveyors require knowledge of the cropping systems, dairy feeding practices, manure storage and spreading norms, and expected nutrient values of feed and manure. For example, although the surveyors were highly involved in question development, and skilled in the nuances of asking questions to elicit farmer responses, they were not dairy nutritionists, and therefore, would probably not know the likely range of feed DM farmers said they offered to their dairy herds. This led to unreasonable data for some farms that needed to be verified during follow-up visits, or discarded. In addition, studies that rely on farmers completing daily manure-spreading logs are most effective when consistent contact is kept with the farmers, including fielding questions, addressing concerns, and encouraging ongoing participation. Such studies represent a valuable source of information about actual nutrient management practices on dairy farms, but they present methodological challenges.

Under current technical and socioeconomic conditions, the appropriateness and adoption of improved feed and manure management systems on dairy farms will depend largely on their profitability and compatibility with existing production practices. Dairy farmers therefore need to be involved in many stages of research and technology development aimed at influencing their practices. Interdisciplinary research, extension, and education activities in partnership with farmers, agribusiness, and policy makers are needed to provide a holistic understanding of factors affecting overall on-

farm nutrient use and how this may be improved in particular production components. A common understanding among stakeholders is needed for information to be integrated and disseminated as recommendations adaptable to farmer circumstances. On-farm data surveys and demonstrations are important steps in this process, provided the farms are representative, and lessons learned are conveyed back to the scientific and policy communities.

ACKNOWLEDGMENTS

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